Personal Exposure to Nitrogen Dioxide and Its Association with Respiratory Illness in Hong Kong[1-3]

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SUMMARY In 1985, 362 primary schoolchildren and their 319 mothers were surveyed in Hong Kong to study the possible relationship of air pollution to respiratory illnesses. Using nitrogen dioxide (NO_2) measured by personal samplers as a measure of air pollution, the study aimed to identify the major sources of NO_2 in the indoor environment and see whether its increased presence was associated with respiratory symptoms. The levels of NO_2 among the mothers was found to increase by 21% if dust exposure was reported from the workplace, 18% if they used such cooking fuels as liquid petroleum gas or kerosene, 11% when kitchens did not have ventilating fans, and 10% when incense was burned at home. In terms of respiratory symptoms, an increase in NO_2 levels of 19% was reported among those with allergic rhinitis and 18% among those with chronic cough. The levels of NO_2 among children were correlated with levels measured in classrooms, all of which had opened windows so that the NO_2 came from outdoors. No association was found between children's NO_2 levels and respiratory symptoms. With the exception of smoking by the father and the children's NO_2 levels, no association was found between smoking at home and NO_2 levels.

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Introduction

Studies on respiratory illness among children in the United Kingdom (1-3) and the United States (4) have found it to be associated with exposure to nitrogen dioxide (NO_2), especially in homes where gas instead of electricity is used for cooking. Exposure to NO_2 has also been found to be associated with lower pulmonary function among children (4). In addition, ambient levels of oxides of sulfur and nitrogen have been correlated with higher rates of chronic cough and phlegm among women in six communities in Japan (5). These data are supported by animal experiments which have shown that mice exposed to NO_2 have higher rates of respiratory infections and lowered ability to clear viable bacteria from the lung (6).

However, epidemiologic data on the effects of NO_2 on respiratory illnesses and pulmonary function are inconsistent (7), with some studies showing no relationship between NO_2 and respiratory illnesses (8-10), or between levels of air pollutants and the results of lung function tests (2,6). The conflicting results on the relationship of air pollution with respiratory illnesses may be partially due to: (*1*) studies that measured NO_2 levels did so by spot measurements of the ambient levels in kitchens, bedrooms, living rooms, or outdoor air and not by cumulative personal exposure levels, and (*2*) the problems of confounding by other sources of air pollutants such as active or passive smoking, cooking fumes, or air pollutants in the workplace.

To explore the possibility that NO_2, a measure of air pollution from combustion, might be related to the high rates of chronic bronchitis among children and mothers in Hong Kong (11), a study was conducted in 1985 in which personal exposure to NO_2 was measured by a badge worn by each subject, and data on respiratory symptoms and indoor sources of combustion were obtained through questionnaires.

Methods

From May 20 to 29, 1985, children attending a coeducational primary school in the Kwun Tong district of Hong Kong were contacted for this study. The school was selected, in cooperation with the local government's Department of Education, to represent subjects from a working class background in an industrial neighborhood of metropolitan Hong Kong. The sample included 390 students in Grades 2 to 6 attending 11 classes in the school. Through the children, the mothers were also asked to cooperate in this study. The response rate was 100% cooperation from the children and 97% from their mothers/guardians. To limit this analysis to mothers and children with complete data sets, the following were excluded from the initial subjects who were contacted: 10 guardians who did not return the questionnaire, 15 guardians who were not related as mother to the child, three mothers who did not return the NO_2 badge, and the redundancy of 43 mothers who had replied more than once because two or more of their children had been included in the survey. Thus, our final sample size for analysis consisted of 319 mothers, with a mean age of 37.9 (SD = 5.6), and their 362 children, with a mean age of 10.0 (SD = 1.5).

A modified version of the questionnaires on respiratory illnesses developed by the British Medical Research Council's Committee on the Aetiology of Chronic Bronchitis (12) and the American Thoracic Society's Division of Lung Disease (13) was used. In the self-completed questionnaire, all subjects were asked whether they had experienced allergic rhinitis, asthma, pneumonia, or chronic cough or phlegm lasting for 3 months or more and unrelated to a cold or flu infection. In addition, the version for the children asked about the occurrence of wheezing and whether they had a runny nose lasting more than 6 months. The version for the mothers included questions on bronchitis, tuberculosis, and other chest diseases. Questionnaires concerning the children were answered by their mothers.

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TABLE 1

NO_2 LEVELS BY AGE AND SEX IN HONG KONG SCHOOLCHILDREN*

Age (yr)	Boys (n)	Boys Mean NO_2 (ppb)	Girls (n)	Girls Mean NO_2 (ppb)	Boys + Girls (n)	Boys + Girls Mean NO_2 (ppb)
7	8	14.14	6	15.45	14	14.71
8	34	15.67	26	15.45	60	15.58
9	21	21.56	34	21.44	55	21.48
10	48	20.18	46	22.17	94	21.15
11	29	22.03	28	24.23	57	23.11
12	36	18.19	35	18.23	71	18.21
13	7	13.34	4	12.49	11	13.03
Total	183	18.48	179	19.77	362	19.12

* Boys versus girls, *t* test p values: for age, p = 0.92; for NO_2 adjusted for age, p = 0.22.

TABLE 2

NO_2 LEVELS BY AGE IN HONG KONG MOTHERS

Age (yr)	Number	Mean NO_2 (ppb)
30 or below	18	21.22
31–35	101	18.87
36–40	124	19.06
41–45	39	20.72
46–50	29	20.27
50 or older	8	17.28
Total	319	19.39

In order to obtain data on indoor sources of air pollution, there were questions on smoking habits of family members, types of heating and cooking fuels, frequency of cooking, ventilation patterns, burning of incense and mosquito coils, and the mother's exposure to dust or fumes in the workplace.

All subjects were asked to wear a badge-type personal sampler pinned to their outer clothing at the upper chest level for 24-h exposure. At bedtime, or when bathing, subjects were instructed to put the badge face-up on an adjacent table so that contact with ambient air was continuous. The badge, measuring 50 × 40 × 7 mm and weighing 15 g, allows for NO_2 to diffuse through five layers of hydrophobic fiber filters before being absorbed on a sheet of triethnolamine solution. The concentration of NO_2 in the sampler was determined by adding a color reagent to the soaked filter and measuring the absorbance of the diazo compound by a spectrophotometer (14). The sensitivity of this sampler is as much as 124.8 μg/h/m³ (66 ppb/h) and has a reported accuracy of ± 20% (15).

Badges (n = 48) were also hung in the classrooms and playground area in the school so that comparisons could be made between ambient indoor and outdoor levels and the personal exposure levels of the children. All classrooms in the six-story school had opened windows for ventilation since the mean outdoor temperature was 27°C and the humidity was 81% during the 2 wk of data collection.

Statistical analyses were conducted by the use of the SPSS-X computer package. The statistical significance of the relationship between different degrees of exposure to sources of air pollution and NO_2 levels was performed using Student's *t* test, if the data were exact, and the ANOVA F-test when the data were categorical. Tests for linear trend for understanding possible dose-response relationships were done by the F-test for linearity (16). Analysis of the correlation between children's and mothers' NO_2 levels, and their relationship to classroom and playground levels, was done using the Pearson's coefficient of correlation, with the *p* value obtained from the one-sample *t* test (16). Stepwise regression coefficients were calculated to determine the contribution of independent sources of indoor air pollution to the cumulative personal exposure levels of NO_2.

Results

The children's NO_2 levels by age and sex are shown in table 1. The higher NO_2 levels among those 9 to 11 yr of age was apparently due to the sampling procedure used during the 2 wk. Children in this age bracket were in Grades 3 to 5, and they were sampled during the first week when the mean ambient level was 21.4 ppb, whereas those in Grades 2 and 6 were sampled the following week when the mean ambient level was 17.8 ppb. These observations are supported by the finding that the mean NO_2 values for all children sampled in the first week was 21.9 ppb versus 16.2 ppb for those sampled in the second week. Because the classes were coeducational, there was no statistically significant difference in age between boys and girls, and there was no difference by sex in their NO_2 levels when matched for class or adjusted by age.

The age distribution and NO_2 levels among the mothers in table 2 show no relationship with age. Analysis by which week the mothers were sampled showed them to have patterns opposite from that of the children. Mothers in the first week had an average level of 17.5 ppb NO_2 versus 21.8 ppb for those in the second week. Generally, the average level of 19.4 ppb for all mothers was not statistically different (p = 0.89) from that of 19.1 ppb among their children by paired *t* test analysis. The mothers' NO_2 badges were exposed 1 day after that of their children so that week of exposure did not affect these results.

When comparing ambient with personal NO_2 levels exposed on the same days, the children's levels were highly correlated with classroom measurements (r = 0.75, p = 0.004). Similarly, classroom levels of NO_2, which were on floors 2 to 5, were correlated with playground levels on the ground floor (r = 0.80, p = 0.03). But correlation of the children's NO_2 levels with playground levels (r = 0.79, p = 0.18) was high but statistically not significant, showing that they spent less time there. If the playground levels are taken as a surrogate measure of outdoor levels on the ground level, the NO_2 levels for the mothers were not associated with the playground levels (r = 0.12, p = 0.46).

In analyzing the correlation coefficent of the mothers' NO_2 with that of their daughters, sons, or all children combined, there was no significant correlation between levels in mothers and that of their children. Although it is possible that boys would tend to spend more time playing outdoors and girls more time playing and helping their mothers at home, there was no difference between the girls and boys in terms of their NO_2 levels and correlation with NO_2 levels in the classrooms or playground.

Environmental Tobacco Smoke

As a result of recent interest in the possible role of environmental tobacco smoke (ETS) as a contributor to NO_2 levels, table 3 shows the levels of NO_2 among children and mothers by the smoking habits of family members. To gather more specific measurements of exposure, the questionnaire asked about the average number of cigarettes smoked at home by family members, and the hours of direct exposure by the child or mother to this smoke. As can be seen, there was no relationship between the child's or mother's NO_2 levels and the number of cigarettes smoked by the father/husband, mother/self, mother + father/mother + spouse, or total number of family smokers per day. Although not shown, there was also no association between their NO_2 levels and the hours they were exposed to cigarette smoke at home or in the workplace.

Stepwise regression analysis of the various independent variables measuring

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TABLE 3

FAMILY SMOKING HABITS AND NO_2 LEVELS

	Children		Mothers	
	(n)	NO_2 (ppb)	(n)	NO_2 (ppb)
Cigarettes smoked by father/husband at home per day, n				
0	233	18.87	201	19.59
1–5	68	18.26	63	19.02
6–10	38	20.65	33	19.55
11+	18	20.60	17	18.25
Trend p value		0.15		0.61
Cigarettes smoked by mother/self at home per day, n				
0	357	19.14	314	19.40
1–5	4	18.45	4	21.33
6+	1	14.47	1	7.68
Trend p value		0.57		0.74
Cigarettes smoked by father + mother/mother + spouse at home per day, n				
0	232	18.85	200	19.61
1–5	68	18.43	63	18.91
6–10	36	20.60	31	19.84
11+	21	20.24	20	18.17
Trend p value		0.17		0.62
Total smokers in the family, n				
0	218	19.00	191	19.77
1	123	19.72	113	19.17
2	16	17.58	12	15.79
3+	5	14.41	3	17.73
Trend p value		0.41		0.16

TABLE 4

STEPWISE REGRESSION COEFFICIENTS OF CIGARETTE SMOKE AND NO_2 LEVELS AMONG MOTHERS AND CHILDREN

Independent Variable	NO_2 Levels	*t* Test p Value
Mothers' NO_2 levels		
Smokers at home, n	−0.714	0.36
Cig/day mother smokes at home, n	−0.488	0.39
Hours mother exposed to smoking at home	−0.100	0.19
	p = 0.22	
Never-smoked mothers' NO_2 levels		
Smokers at home, n	−0.977	0.23
Hours mother exposed to smoking at home	−0.106	0.17
	p = 0.13	
Children's NO_2 levels		
Smokers at home, n	−0.775	0.26
Hours child exposed to smoking at home	−0.147	0.61
Cig/day father smokes at home, n	0.205	0.02
Cig/day mother smokes at home, n	−0.220	0.61
	p = 0.21	

levels of smoking in the home is shown in table 4. It is interesting to note that increased smoking generally led to *reduced* levels of NO_2 among mothers and children. The only exception was data on the number of cigarettes smoked by the father per day in which each cigarette smoked contributed to an average increase of 0.2 ppb of NO_2 in the exposed child. This exception, coupled with the fact that NO_2 levels were not higher among five mothers who were currently smoking at the time of the survey, seems to indicate that other factors were affecting this relationship.

The overall tendency for NO_2 levels to decrease as the number of smokers or cigarettes smoked in the home increased might be due to compensation behavior. That is, as family members smoked and polluted the air at home, increasing measures of ventilation would be taken by the mother, such as opening windows, turning on fans, etc. The exception of father's cigarettes on children's NO_2 levels may have arisen because they were less concerned with opening windows and reducing smoke inhalation by their children. Because the wife's NO_2 level was found to decrease as her husband smoked more at home, this seems to indicate that the children's exposure to the father's tobacco smoke occurred when the mother was not in the same room and in a position to increase ventilation. As this study was done in 1985, before publicity and public awareness of the possible health hazards of environmental tobacco smoke, these findings seem consistent with the expected behaviors of Chinese parents. Smoking among primary school children is also rare in Hong Kong, so the effects of active smoking by children was probably negligible on these results.

Cooking and Heating Habits

The most common types of fuel used for cooking and heating water were bottled liquid petroleum gas (LPG), piped gas, and kerosene. None of the surveyed households had electric stoves because electricity is a more expensive source of energy and its lack of immediate heat control makes it less conducive for Chinese cooking. Although LPG and piped gas were the major sources of fuel used in the kitchen, it was also common for some households to use the cheaper but smellier kerosene stoves as a supplemental source of energy for cooking or room heating.

It can be seen in table 5 that the children's NO_2 levels were not affected by the type of fuel used in the home. This probably reflected the tendency for children to spend little time in kitchens, which were usually very small (25 ft^2) and frequently just a makeshift corner of a balcony. Among mothers, however, NO_2 levels were highest for LPG and kerosene users and lowest for those with piped gas, and these findings were statistically significant. The greatest difference of 3.8 ppb was found between those who used only piped gas and those who did not (p value < 0.001).

To estimate the mother's exposure to combustion during cooking, table 6 shows her NO_2 levels by the frequency she cooked meals or fried food per day in the presence or absence of mechanical ventilation in the kitchen. Ventilation was defined as the use of a mechanical fan in a fume hood or on a window to disperse fumes from the kitchen to outdoors. Because the Chinese style of frying generates large amounts of smoke and oil fumes, most households (79%) used them, and the NO_2 levels of mothers in kitchens with such types of mechanical ventilation were significantly lower than those without by an average of 2.3 ppb. It can also be seen that if ventila-

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TABLE 5

TYPES OF HOUSEHOLD COOKING AND HEATING FUELS AND NO_2 LEVELS

	LPG Only		(LPG + Kerosene) Only		Kerosene Only		Piped Gas Only	
	Yes	No	Yes	No	Yes	No	Yes	No
Children								
Exposed, n	148	214	69	293	27	335	113	249
Mean NO_2, ppb	19.53	18.84	19.16	19.11	17.66	19.24	19.14	19.11
t test p value	0.31		0.95		0.21		0.97	
Mothers								
Exposed, n	127	192	62	257	24	295	102	217
Mean NO_2, ppb	20.52	18.64	21.36	18.91	19.43	19.38	16.84	20.59
t test p value	0.04		0.09		0.97		0.000	

Definition of abbreviation: LPG = liquid petroleum gas.

TABLE 6

EFFECT OF FREQUENCY OF COOKING AND VENTILATION ON MOTHERS' NO_2 LEVELS

	Ventilation during Cooking*				
	Yes		No		All
	(*n*)	(NO_2, ppb)	(*n*)	(NO_2, ppb)	(NO_2, ppb)
All kitchens	253	18.90	66	21.24	19.39
t test p value		0.01			
Meals cooked per day, n					
0	6	19.06	13	20.13	19.79
1	36	17.76	3	21.51	18.05
2	122	18.70	23	21.44	19.13
3	89	19.64	27	21.58	20.09
Trend p value		0.30		0.54	0.34
Meals where food is fried per day, n					
0	11	19.05	12	19.55	19.31
1	150	18.56	28	21.32	18.99
2	78	19.26	22	21.70	19.80
3	14	20.46	4	23.27	21.08
Trend p value		0.43		0.30	0.31

* Fume hood or ventilating fan used in kitchen.

tion was present, the mother's NO_2 levels were not noticeably increased if she cooked more meals or fried food more often per day. However, among mothers without ventilated kitchens, there was a trend toward increasing NO_2 with more frequent frying, although this was not statistically significant.

Because piped gas and mechanical ventilation are likely to be present together, table 7 shows the effects of both variables on NO_2 levels. Eighty-seven percent of the households with piped gas had ventilation fans, whereas this was apparent in only 76% of those who used other types of fuel. The presence of ventilation fans especially lowered NO_2 levels among households without piped gas.

In an analysis of children's cooking activities with NO_2 levels, which took into account the greater participation of girls (21%) than of boys (10%), there was no association between cooking activities, the presence of ventilating fans, and NO_2 levels, as shown in table 8.

TABLE 7

EFFECTS OF VENTILATION AND PIPED GAS ON MOTHERS' NO_2 LEVELS

	Ventilation during Cooking*				
	Yes		No		*t* Test
	(*n*)	(NO_2, ppb)	(*n*)	(NO_2, ppb)	p Value
Piped gas used					
Yes	89	16.77	13	17.26	0.82
No	164	20.06	53	22.22	0.05
t test p value		0.01		0.002	

* Fume hood or ventilating fan used in kitchen.

Burning of Incense or Mosquito Coils

Because about half of the households in Hong Kong burn incense daily for religious reasons, and one-eighth burned mosquito coils in the summer period, the questionnaire asked whether these items had been burned in the previous 24 h to coincide with the sampling of personal NO_2 levels. It can be seen in table 9 that the children's NO_2 levels were unaffected by such sources of burning, but among the mothers, those who did burn incense had higher NO_2 levels by 1.9 ppb than those who did not ($p = 0.04$).

Workplace Exposures

To assess the contribution of workplace exposures to the mothers' NO_2 levels, table 10 shows that their NO_2 levels increased as self reports of exposure to occupational dust increased in severity. For those who reported high levels of such exposure, their NO_2 levels were 4.0 ppb higher. However, such a trend was not found for exposure to fumes or gases in the workplace. In a subtropical climate such as that in Hong Kong where high heat and humidity encourages quick decomposition of organic matter, the sources for some of the fumes and gases could have come from rotting food and moldy growths. Noncombustible chemicals used in the electronics industry, which is a major employer of these women, could have also contributed to the reports on fumes.

Respiratory Symptoms and NO_2 Levels

The mean NO_2 levels among those reporting the presence or absence of nine different respiratory symptoms is shown in table 11. Among the 312 mothers who had never smoked, those reporting to have allergic rhinitis had a mean NO_2 level of 22.6 ppb versus 19.0 ppb among those who did not, and the *t* test p value was 0.002. An increase in NO_2 levels was also associated among mothers reporting positively for chronic cough, as they had NO_2 measurements of 22.5 ppb versus 19.1 ppb among those without (p value = 0.05). Among the children, there were no statistically significant differences in NO_2 levels by presence versus absence of the respiratory symptoms.

To assess the association of multiple respiratory symptoms to NO_2 levels, table

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TABLE 8

EFFECTS OF VENTILATION AND COOKING ON CHILDREN'S NO_2 LEVELS

	Ventilation during Cooking					
	Yes		No		t Test	All
	(n)	(NO_2, ppb)	(n)	(NO_2, ppb)	p Value	(NO_2, ppb)
Boys help cook						
Yes	14	20.17	5	16.96	0.39	19.33
No	130	18.74	34	17.01	0.17	18.38
t test p value		0.38		0.99		0.52
Girls help cook						
Yes	30	18.81	9	21.66	0.29	19.47
No	112	19.74	28	20.31	0.69	19.86
t test p value		0.50		0.60		0.75

TABLE 9

EXPOSURE* TO INCENSE OR MOSQUITO COILS AND NO_2 LEVELS

	Incense Burned at Home		Mosquito Coil Burned at Home	
	Yes	No	Yes	No
Children				
Exposed, n	177	185	52	310
Mean NO_2, ppb	19.57	18.69	18.73	19.19
t test p value	0.19		0.63	
Mothers				
Exposed, n	154	165	43	276
Mean NO_2, ppb	20.36	18.48	19.69	19.34
t test p value	0.04		0.79	

* Incense or mosquito coils were burned during the 24 h that the NO_2 badges were worn.

TABLE 12

MULTIPLE RESPIRATORY SYMPTOMS PER SUBJECT AND NO_2 LEVELS

Respiratory Symptoms (n)	Children*		Never-smoked Mothers†	
	(n)	Mean NO_2 (ppb)	(n)	Mean NO_2 (ppb)
0	244	19.26	230	18.83
1	61	18.70	52	19.92
2	25	17.59	19	22.95
3	12	21.52	7	21.79
≥ 4	9	19.15	4	24.57
Trend p value	0.92		0.01	

* The presence of the following, apart from those caused by colds/flu: allergic rhinitis, asthma, chronic cough, chronic sputum, pneumonia, runny nose, and wheeze. Data from one child was deleted because it was incomplete.

† The presence of the following, apart from those caused by colds/flu: allergic rhinitis, asthma, bronchitis, chronic cough, chronic sputum, pneumonia, and tuberculosis.

12 shows that there was no dose-response effect among the children, but there was a significant trend ($p = 0.01$) among mothers who had never smoked. Mothers who had four or more of the following symptoms: chronic cough, chronic sputum, asthma, pneumonia, allergic rhinitis, tuberculosis, or bronchitis, had NO_2 levels that were 5.7 ppb higher than those who had none.

The indoor sources of combustion that were previously evaluated and had statistically significant associations with levels of NO_2 among mothers are summarized in table 13.

Discussion

This study of 319 mothers and their 362 children attending a primary school in the Kwun Tong district of Hong Kong had three aims: (*1*) identify indoor sources of combustion in working class households, (*2*) assess their possible contribution to levels of NO_2 as measured by personal passive samplers, and (*3*) examine whether higher NO_2 levels were associated with self reports of respiratory symptoms.

The major sources of combustion in Hong Kong homes were fires from cooking food, heating water, burning religious incense and mosquito coils, and the smoke from cigarettes. Outdoor sources of NO_2 came from motor vehicles, factories, restaurants, incinerators, aircraft, etc. Because the children's NO_2 levels were significantly correlated with ambient levels, and were less affected by home sources of combustion, these data suggest that most of their NO_2 came from outdoor sources. By contrast, their mothers NO_2 levels were dependent on their indoor activities. If they had piped gas and mechanical ventilation in the kitchen, their levels of NO_2 were reduced by 18 and 11%, respectively. But their NO_2 levels increased by 10% if incense was burned at home, and by 21% if they reported high

TABLE 10

OCCUPATIONAL EXPOSURE TO GAS OR FUMES AND NO_2 LEVELS AMONG HONG KONG MOTHERS

Exposure	Number	Mean NO_2 (ppb)
Dust		
None	248	18.93
Low	40	19.51
High	31	22.92
F-test p value*	0.04	
Fumes		
None	282	19.56
Low	24	18.16
High	13	17.97
F-test p value*	0.59	

* One-way ANOVA F-test among groups with different exposures.

TABLE 11

RESPIRATORY SYMPTOMS AND NO_2 LEVELS

	Children					Never-smoked Mothers				
	Yes		No		t Test	Yes		No		t Test
Symptom	(n)	(NO_2, ppb)	(n)	(NO_2, ppb)	p Value	(n)	(NO_2, ppb)	(n)	(NO_2, ppb)	p Value
Allergic rhinitis	33	18.75	329	19.16	0.75	37	22.62	275	18.97	0.002
Asthma	29	20.07	333	19.04	0.42	4	20.60	308	19.39	0.77
Bronchitis	–	–	–	–		24	21.56	288	19.22	0.18
Chronic cough*	52	19.12	309	19.12	0.99	25	22.50	287	19.13	0.05
Chronic sputum*	41	17.53	321	19.32	0.10	30	20.47	282	19.29	0.45
Pneumonia	28	19.91	334	19.05	0.56	3	21.68	309	19.38	0.63
"Runny nose"†	13	17.16	349	19.19	0.28	–	–	–	–	
Tuberculosis	–	–	–	–		5	19.43	307	19.40	0.99
Wheeze	34	20.07	328	19.02	0.39	–	–	–	–	

* Symptoms reported apart from those associated with colds/flu for children, and lasting > 3 months for mothers.

† Mucoid or purulent discharge from the nose > 6 months.

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TABLE 13

SUMMARY FACTORS ASSOCIATED WITH NO_2 LEVELS IN MOTHERS

Factor	Yes versus No Difference in NO_2 Levels (ppb)	(%)*	t Test p Value
Dust at work, high versus none	3.99	21.1	0.01
Use piped gas for cooking	−3.75	−18.2	0.000
Mechanical ventilation in kitchen	−2.34	−11.0	0.02
Burn incense at home	1.88	10.1	0.04

* (Yes NO_2 ppb minus No NO_2 ppb) divided by Yes NO_2 ppb.

levels of dust at work. However, despite their different sources of NO_2, the mean levels of NO_2 between mothers and children were not significantly different, whether in paired or group analysis.

These results were dependent on the NO_2 badges being properly exposed, and on mothers being able to give an accurate account of their exposure to sources of combustion and experiences with respiratory illnesses. The children were instructed on how to use the badges, and attached and removed them from their clothing under the guidance of field workers to minimize mishandling. Although there are always problems of inaccurate reporting in self-completed questionnaires, because the mothers' NO_2 levels were found to increase as their exposure to fires in the home increased, this indicated that the data based on NO_2 badges and recall were generally accurate. Yet it is also possible this is a result of bias. Mothers more conscientious in reporting exposure to combustion and respiratory illnesses might have exposed their NO_2 badges for longer periods of time or placed them more closely to sources of combustion. We tried to minimize this problem by not informing the mothers what the badge was measuring.

When the Hong Kong NO_2 exposure levels were compared with those from other studies that used a similar type of NO_2 personal badge monitoring system, the level for Hong Kong subjects at 19 ppb was moderately low. A study of volunteers from 3 Asian cities in February 1983 found NO_2 levels among subjects from Bangkok to be 12 ppb, Manila 14 ppb, and Tokyo 36 ppb (17). Another study conducted from January to February 1982 in Tokyo recorded mean NO_2 levels of 36 ppb among primary schoolchildren (18) and 47 ppb among their mothers (19).

These data indicate that climatic factors heavily influence indoor levels of NO_2. The study by Mori and coworkers (17) showed that in temperate zone climates such as that in Japan, where home heating and insulation reduces the dispersion of air pollutants from indoor sources of combustion, indoor levels of NO_2 at 48 ppb in the winter were twice as high as outdoor levels at 21 ppb. By comparison, in tropical climates such as those in Bangkok and Manila, indoor levels of NO_2 at 10 and 13 ppb, respectively, were lower than the outdoor levels of 13 and 14 ppb.

Hong Kong's situation is similar to that of Bangkok and Manila in being a semitropical climate, so windows are kept open throughout the year and there is little accumulation of air pollutants from home-generated sources. However, unlike Bangkok and Manila, outdoor levels of NO_2 may not be simply higher than indoor levels in Hong Kong. This is because most of the Hong Kong subjects reside, study, and work in multistory buildings, which are less common in these other cities, and outdoor levels of NO_2 were found to decrease with increasing height of a building. In our survey of the school, the following mean levels were measured at the following heights: ground-floor playground, 25 ppb; second-floor classrooms, 19 ppb; third-floor classrooms, 21 ppb; fourth-floor classrooms, 20 ppb; and fifth-floor classrooms, 19 ppb. Another study of ambient NO_2 levels by the Hong Kong Government's Environmental Protection Agency (20) found that the ratio of ground to twelfth floor levels was 1.46 (i.e., 38 to 26 $\mu g/m^3$). For the Hong Kong mothers, the average home was located on the twelfth floor of a building so that, generally, NO_2 levels were likely to be lower indoors than outdoors if no combustion was taking place in the home. This factor also reduces the possibility that the higher NO_2 levels among mothers with allergic rhinitis or chronic cough was simply due to their greater tendency to stay indoors.

When we analyzed data on ETS and NO_2, the mothers' NO_2 levels were unaffected by their own or other people's smoking habits at home or in the workplace. However, we only had five mothers who claimed to be currently smoking. Another international study on ETS and urinary cotinine/creatinine ratios (21), which included 102 Hong Kong women who claimed to be nonsmokers, one-fourth of whom were mothers in this study, indicated that one Hong Kong subject had ratios above 100 ng/mg, and six had ratios above 50 ng/mg. Thus, the possibility of deception on smoking habits varied from 1 to 6%, and would be too small to influence the NO_2 levels.

The children's NO_2 levels increased with the number of cigarettes their fathers smoked at home, but they were unaffected by hours of exposure at home, the number of cigarettes smoked by their mothers, or the number of smokers at home. This general lack of an effect of active or passive smoking on NO_2 levels was also found by Matsuki and coworkers (22) in their study of primary school children and mothers in Japan.

Our results also point to some of the advantages and disadvantages of measuring NO_2 by passive personal samplers. The NO_2 data reflected personal cumulative exposures over the 24-h period sampled, and thus is an improvement over previous studies (3, 4, 8) in which monitoring machines were placed in fixed positions in kitchens, living rooms, or bedrooms in the home. The latter method provides indirect measures of personal exposure since people do not stay in one position or in one room over a daily or weekly period. On the other hand, we were unable to account for high peaks of NO_2 exposure, which may reach up to 1 ppm (4) when gas stoves are turned on for cooking. This may help explain why respiratory symptoms were not associated with NO_2 levels in children, but were found for allergic rhinitis and chronic cough in mothers. The children's levels reflected a continuous exposure to moderate background levels of NO_2 since they had little direct contact with fires. Their mothers, however, were exposed to acute high levels of NO_2 when burning occurred in the home, and low background levels at other times. These short-term, acute exposures to high levels of NO_2 might trigger allergic rhinitis symptoms in the mothers because NO_2 is a respiratory irritant (23). The symptoms of chronic cough in mothers might also have been a result of long-term exposure to NO_2, which the children had not had.

In comparing our results on respiratory symptoms with findings from other

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studies, our data agree with those found by Keller and coworkers (8), Melia and colleagues (3), and Ware and coworkers (10) in that respiratory illnesses in children were not associated with their exposure levels to NO_2. Our study was also able to assess personal levels of NO_2 exposure, which is an improvement over other studies that based NO_2 levels on the type of cooking stove in the home (24).

The comparability of our data with others is also complicated by the fact that Chinese cooking styles differ from those in the West. Foods are usually stir-fried over high heat for a short time, and the subsequent production of oil and smoky fumes almost necessitates good ventilation in the kitchen. By contrast, cooking in the West is commonly done by turning on the oven for hours at a time. Therefore, the total duration of combustion is shorter, resulting in lower NO_2 levels in Hong Kong households. Moreover, no one used the kitchen stoves for home heating or clothes drying. Thus, our overall levels of NO_2 may be lower than in other studies done in temperate-zone climates. This seems supported by the fact that the Hong Kong mothers' mean NO_2 level of 19 ppb was less than half that of the 47 ppb measured for Japanese mothers (19).

The inconsistent findings in the literature may also be affected by lack of emphasis on the role of ventilation in homes. In our data, the use of ventilating fans reduced NO_2 levels significantly, especially in the presence of more polluting types of fuel such as liquid petroleum gas and kerosene. Thus, the assumption that a gas stove will increase personal exposures to NO_2 needs more refinement. A similar situation was suggested by our data on environmental tobacco smoke. Increasing levels of smoking at home tended to decrease NO_2 levels, possibly because as the indoor air was polluted by smoking, more measures were taken to ventilate the room.

Our study did find that among mothers with no history of smoking, NO_2 levels were higher by 3.4 ppb among those with chronic cough, and by 3.7 ppb among those with allergic rhinitis. The association of NO_2 with cough and phlegm (5) and allergic rhinitis (25) was also found in two Japanese studies even though both used outdoor measurements of NO_2. Moreover, a study of nonsmokers in Maryland found such symptoms associated with gas stoves (26).

The possible link between NO_2 and respiratory symptoms in nonsmoking adults is further supported by our finding of a dose-response relationship ($p = 0.01$) between NO_2 levels and the number of respiratory symptoms reported by mothers. Mothers with four or more symptoms had mean NO_2 levels 30.5% higher than did those with none. Because the NO_2 exposure measurements were unknown to the respondents, these correlations suggest that the association is not due to recall bias and support the possibility that long-term chronic exposures to NO_2, or an associated by-product of combustion, may be deleterious to the respiratory health of adult nonsmokers.

The biologic mechanisms for such an effect are difficult to explain since most of the published research is based on very high exposure levels. Studies on rats have shown morphologic changes in their lungs after NO_2 exposures of 25 ppm or more. At lower and continuous exposures of 2 ppm of NO_2, only slight destruction of the rat's bronchiolar epithelium and loss of cilia was noted, and these slight changes did not affect their survival or progress to fatal lung disease (23). In human occupational exposures, it is known that there is a delay of 3 to 30 h before the onset of respiratory symptoms, and concentrations of NO_2 need to reach 60 ppm for throat irritation and 100 ppm for cough (27). It is doubtful that such high exposures to NO_2 were encountered in Hong Kong homes. Yet the long-term health effects of low levels of exposure to NO_2, possibly resulting in chronic obstructive bronchitis or emphysema in humans, are still uncertain.

In our previous report (11), we discussed the possibility that respiratory diseases such as allergic rhinitis, asthma, bronchitis, pneumonia, or tuberculosis were more likely to be underreported than were respiratory symptoms such as cough, phlegm, and wheezing. This is because the former are labels generally given by a doctor, and the latter are labels used by the lay public. In this population, knowledge of medical terms is limited because doctor-patient communication is poor. The recall of respiratory illnesses, however, was quite homogenous among these subjects since our previous report (11) showed that the frequency of reported respiratory illnesses did not vary with household density, i.e., number of persons per room, which is an indicator of socioeconomic status. This suggests that the observed associations between NO_2 levels and respiratory symptoms are not explained by a tendency of mothers with higher socioeconomic status to be more likely to report symptoms and more conscientious about exposing NO_2 badges. It seems more likely that underreporting of respiratory diseases in this population reduced the possibility of finding a dose-response effect of NO_2.

It is also possible that other factors such as diet may confound the relationship between respiratory symptoms and NO_2 levels. In a previous study on Hong Kong Chinese women who had never smoked, those with symptoms of chronic cough and phlegm were more likely to consume cured meats and alcohol and less likely to consume vegetables, fresh fruit, and milk (28, 29). Although it is speculative, it would seem possible that in some communities in the West, gas cooking could be associated with the higher risk diet since it is more likely to be found in older and therefore poorer homes than those with electric stoves. Certainly in Hong Kong, electric stoves were introduced about 5 yr ago, and they are installed only in the most expensive "luxury" housing units.

In conclusion, these results indicate that in a cross-sectional study of a community, measuring personal exposures to NO_2 allowed us to identify important sources of it, evaluate the effects of mechanical ventilation, and discriminate adults at higher risk for respiratory illnesses from home or workplace exposures. However, the usefulness of NO_2 as an indicator of air pollution may be limited in studying the health effects of ETS since the respirable particulate matter from ETS seems to be more important for health than gases such as nitrogen oxides (30). On the other hand, measuring NO_2 can validate reports of exposure to air pollutants coming from other sources of combustion. In our study, women who reported high levels of dust in the workplace also had increased levels of NO_2, suggesting that some of the dust was generated from combustion. However, since NO_2 is only one by-product of combustion, it is possible that other unmeasured, but correlated, by-products of combustion, e.g., particulates, carbon monoxide, polycyclic aromatic hydrocarbons, etc., may be responsible for the health effects attributed to NO_2 in this study.

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